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Automatic Resource Based Cost-Time Forecasts

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INTRODUCTION

It has been strongly argued (Beeston, 1987; Brandon, 1982) that conventional models of construction cost and time are fundamentally inadequate for strategic project management and design decisions. Two major flaws are apparent. Firstly, they lack an all important direct link between development/design decisions and the resulting construction process. Secondly, they do not explicitly encapsulate the uncertainties inherent in the construction process.

Until recently, the difficulties in overcoming these problems in competitive bidding situations have been thought to be insurmountable as the delayed involvement of the contractor in the decision process excludes the expertise necessary to assess the production implications of design decisions. New technology however, in expert and knowledge based systems (KBS), offers a potential solution in enabling this expertise to be accessed through computer simulation at an earlier stage than is usually possible. The potential of KBS to replicate contractors' production planning skills, together with non-deterministic methods to model the uncertainties involved, provides the basis for a powerful new approach to cost-time forecasting.

The first part of this paper provides a back to the approach in reviewing some recent work in probabilistic cost time forecasting and the use of KBS in construction planning. The second part examines the potential for combining this work, and outlines a prototypical system currently under development at the University of Salford.

SIMULATION MODELS IN CONSTRUCTION COST-TIME FORECASTING

There has been a great deal of research interest recently in the potential of production plan based stochastic simulation models for construction cost-time forecasting. A number of systems have been postulated (Baxendale, 1984; Bowen et al, 1987; Jackson, 1986; Legard, 1983; Newton, 1983; Pohl and Chapman, 1987), and in the UK at least two have been developed into working prototypes.

One of these, CPS, the Construction Project Simulator (Bennett & Ormerod, 1984) developed at Reading University, employs a hierarchy of Gantt chart production plans, runs on a microcomputer, and uses Monte Carlo stochastic simulation to generate cost-time frequency distributions from probabilistic activity times. Interference to the production process due to factors such as weather or late instructions are also simulated probabilistically. A comprehensive range of probability functions is available in the system, some of which are pre-selected (e.g. weather conditions) but mostly for user selection. Output is in the form of automatically generated histograms, cumulative frequency distributions, etc., but all the activities, precedences, costs, time parameters, and many of the probability distribution parameters have to be input by the user.

Another system of this type is CASPAR, Computer Aided Simulation for Project Appraisal and Review, (Thompson and Willmer, 1985), developed at the University of Manchester Institute of Technology. This is a project management system aimed essentially at risk assessment of strategic development decisions for major engineering schemes. The system is able to provide investment appraisals over the whole of the project operating life and has been used to generate detailed operational type cost-time estimates for high risk construction contracts. There is also a useful facility to define corrections between the sampled variables. The basis of the system model is a network plan which can be evaluated using Monte Carlo methods although as yet only 20 stochastic variables are available. Output can be in graphical form, as frequency distributions, but input to the system is largely a manual process.

Although generally fulfilling their intended purpose, these systems have several significant limitations that restrict their practical application for cost-time forecasting:

1. An operational plan for the construction work must be prepared manually. At the critical formative stages of a project the knowledge necessary to formulate such a plan is not normally accessible and the conventional construction planning techniques that have to be used are rather detailed and time consuming.

2. Probability distributions must be defined for all significant variables in the systems. Empirically derived data is extremely sparse and the user often has to resort to subjective assessments of the probability distributions needed. Like 1. above, this process requires considerable skill and experience.

3. The key aspect of management control during the construction process is not represented in the system. Essentially therefore, these are random walk models and as such tend consistently to over-estimate the dispersion of potential outcomes.

4. Many users have difficulty in interpreting output from the systems which is not generally in an accustomed format.

AUTOMATING THE FORMULATION OF CONSTRUCTION PLANS

Current construction planning relies upon the manual formulation of plans and is usually performed in an intuitive and unstructured fashion with considerable reliance on engineering judgement (Hendrickson et al, 1987b). The generation of PERT/CPM networks has to be painstakingly performed by engineers working directly from the project drawings with few computer based aids other than general project templates or past project networks that can be adapted to new projects.

Automated planning, however, has been a feature of artificial intelligence (AI) research since Newell and Simon (1972). This defines the planning task as that of predetermining a transformation process by the choice of an action set that, when arranged chronologically, will eventually convert some initial situation into a "goal" situation. Plans can be either linear, where each activity is treated strictly in sequence, or nonlinear (typical of construction operations), where activities may occur in parallel (Nillson, 1980; Sacerdoti, 1975). NOAH (Sacerdoti, 1975), an early goal seeking nonlinear planning system, used a set of procedures termed "critics" to identify unfavourable interactions between different parts of the plan, but without any facility to backtrack from "bad" decisions. NONLIN (Tate, 1977), an extension of NOAH, was developed to detect interactions by analysis of the underlying goal structure and, with the inclusion of backtracking, applied to a construction project planning problem. More recently, MOLGEN (Stefik, 1980), has been developed to use constraint generation and posting to reduce backtracking in genetic applications. Other systems that plan with temporal constraints include DEVISER (Vere, 1983), for planning the operation of space probes, and NUDGE (Goldstein & Roberts, 1977), a meetings schedule planner.

Several construction specific automated planning systems have been reported using knowledge based systems (KBS) technology:

- PLATFORM (Levitt & Kunz, 1985), for off-shore platform construction, updates either network attributes (eg. durations) or topology as information concerning the actual duration of activities is received. Topology alteration is achieved by choosing among several alternative predefined sub-networks of major activities.

- CONSAS (Ibbs and De La Garza, 1988) for medium/-high-rise reinforced concrete buildings, analyses construction schedules by means of a knowledge base consisting primarily of scheduling decision rules, construction "common sense" knowledge, and construction knowledge developed or used by the experts when planning a project. An important characteristic of the system is its utilisation of sophisticated existing software for the expert system (Personal Consultant Plus), project control (Primavera Project Planner) and database (dBASE III Plus). A more substantial version is under development which replaces PCP with the more powerful ART, uses object oriented programming and allows interfaces to cost, schedule, and quality control modules of a broad project control system.

- CONSTRUCTION-PLANEX (Hendrickson et al, 1987b) suggests technologies, generates activities, determines precedences, estimates durations, and produces a complete plan, provisional schedule and cost estimate for the ground works and frame of a modular high rise building system. The program's knowledge base is derived from a large number of sources, each input as decision tables and converted into a network of frame schemes. The system is also said to provide a good user interface and impressive graphics.

- LIFT-2 (Bremdal, 1987) generates plans for heavy-lift operations using a hierarchy of goals, constraint satisfaction, and a trial and error facility in seeking the achievement of goals and subgoals.

- GHOST (Navinchandra et al, 1988) is a prototypical network generator which relies on an input set of activities for schedule production. This is done incrementally by first assuming a naive nonlinear solution for correction by a set of knowledge based "critics" which "know" about basic physics, construction norms, network redundancy, etc. GHOST does not extract activities from drawings or estimate durations.

- BUILDER (Sriram et al, 1989) automates the generation and maintenance of schedules from architectural drawings. It has three components: a drawing interface, a construction planning expert system and a CPM algorithm -- which are implemented as a layered knowledge base. The drawing interface provides graphic input from an architectural plan, identifies and classifies the building components present and extracts the geometric features of the building to produce a semantic network representation of the drawing. The construction planning KBS utilises an object-base and rules about construction method to generate precedence relationships, and through a conventional database generates quantities and costs. The CPM employs both object oriented and conventional algorithms to maximise efficiency.

- MIRCI (Alshawi & Jagger, 1989) is another prototypical system for construction planning. MIRCI comprises three main integrated software components: (1) a KBS activity generator, using the Leonardo Level 3 shell, (2) data storage, using Dbase III, and (3) project planning software, using Pertmaster Advance. The activity generator operates at three levels: (1) the executive level which identifies functional (design) elements, (2) an intermediate level which relates functional elements to their corresponding constructional activities, and (3) a final level (still under development) which takes into account all possible site conditions, available resources and weather conditions. The system is said to have a friendly user interface.

DISCUSSION

These developments in the automation of construction planning offer potential solutions to some of the limitations identified earlier to the application of production plan based simulation models in cost-time forecasting.

Firstly, automation not only offers a means of speeding up and easing the process of formulating the key operational plan, but a KBS approach enables the task to be undertaken by users without specific construction planning expertise.

Secondly, the facility to automatically modify or update the operational plan offers a potential to simulate the effect of production management control decisions that take place during the construction process. Outside the field of construction, some work has already been done on the use of expert systems in the control of discrete event simulations. Of particular interest is the identification by Flitman and Hurrion (1987) of the potential for developing the knowledge base for such automatic control mechanisms through the process of learning by parameter adjustment.

There is a further role for knowledge based systems outside automatic planning. As identified earlier, one of the major constraints upon the practical application of production plan based simulation models is in the acquisition of empirical data for the specification of probability distributions for the variables used in Monte Carlo simulation. Hendrickson et al (1987a) have pointed the way towards the use of a knowledge based system in the assessment of activity durations, through the use of a rule based system to apply modifications to standard data according to the context of application.

One further field of development is worthy of mention. A recent survey by Bell (1985) has identified the importance of visually interactive modelling (VIM), and particularly visually interactive simulation (VIS) as problem solving aids. Of special relevance to simulations involving "real time" dynamic changes, such as in replanning as a response to production control decisions, is the work of Alemparte et al (1975) and Palme (1977) in using simulation driven moving displays. The reported success in the use of such techniques as a means of communicating the state of the simulated process to the user suggests that this may be an approach of great potential for project managers, who are known to rely on sets of key performance indicators and exception reporting mechanisms for status assessment (Ibbs and De La Garza, 1988).

The potential therefore exists to bring knowledge based systems and stochastic simulation together into an intelligent simulation system to provide construction cost-time forecasting which is production (resource) based and non-deterministic, and which includes the facility to emulate real time management control of the production process. With such a system, design information may be input to automatically generate probabilistic cost-time data, via simulation iterations. User modifications to design can then be assessed in terms of cost-time until a satisfactory design solution is found. Alternatively, the production control function may be modified as a means of assessing potential production management strategies. Thus, by unifying the design and production functions, the user is able to investigate both aspects simultaneously.

Figure 1 shows the actions of the system in schematic form.

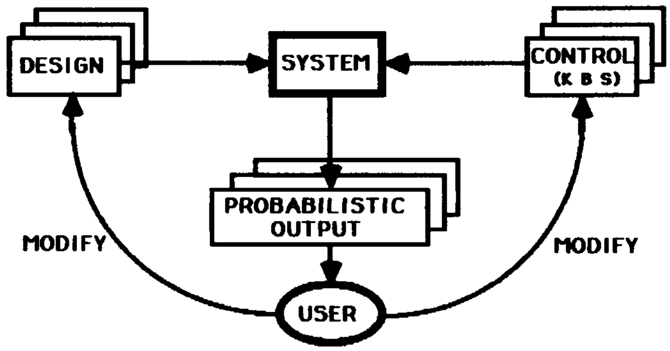

Figure 1 — System Action

The fundamental benefit of this approach is the provision of a crucial link between design decisions and construction processes, together with the risk assessment facility offered by the probabilistic output. The system offers a unique potential to identify and compare alternative development, design and production strategies in terms of the cost/time implications to all those involved.

SYSTEM SCHEMA

A prototype system is currently under development at Salford University, for the purpose of assessing the feasibility of intelligent simulation techniques in construction cost-time forecasting. In this work it is recognised that both simulation modelling of construction processes and automatic construction planning are in their infancy. Initial studies have suggested that an appropriate development vehicle would be multi-unit construction projects in the remodelling/renovation field. Such schemes are characterised by uncertainty and sensitivity to effective operational planning, but at the same time the repetition of construction processes across multiple units makes the planning problem more tractable.

The general form of the system under development is shown in Figure 2.

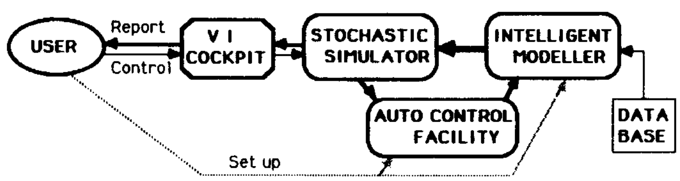

Figure 2 — System Schema

In outline its operation is as follows:

1. The intelligent modeller comprises a KBS driven construction plan generator together with a KBS based activity duration estimator. Both components draw basic source data, relating activities to resources and providing time and cost rates, from the database. The modeller feeds the stochastic simulator which repeatedly evaluates the construction plan by random sampling from the activity time/cost probability distributions provided by the modeller.

2. An automatic control facility monitors the simulation runs and emulates the management control decisions of the construction manager, briefing the modeller to amend the construction plan accordingly. This facility is one of the most significant features of the system through its introduction of dynamics to the topology of the production plan.

3. The user sets up the system by inputting the necessary project specific information on design, context and the required production management strategy.

4. The visual interactive (VI) cockpit provides output from the simulation runs in a monitoring and reporting role. It further provides the opportunity for the user to stop the stimulation run and to redirect it if necessary with changed or additional requirements.

Current system development is intended to assess feasibility rather than produce a full working system, and so knowledge based system development is limited to the production of skeletal systems capable of evaluating potential.

The stochastic simulator follows the model of the Construction Project Simulator (Bennett and Ormerod, 1984) in being built to incorporate both variability in activity times and interferences to the production process. However, for simplicity, only beta and triangular distributions are being incorporated, because they can be defined by relatively accessible estimates of "most likely,""optimistic" and "pessimistic." However the system architecture is being designed to allow future developments to encompass a wider range of distribution forms.

The activity duration estimate module follows the approach adopted by Hendrickson et al (1987a), but is being built to operate on the three parameter estimates required to define probability distributions for the activities.

In addition to conventional knowledge acquisition techniques, it is intended that the control facility will be developed using the partly completed system as a vehicle for knowledge elicitation. Expert construction managers will "manage" simulation runs using the VI cockpit. The KBS will then be developed through the process of learning by parameter adjustment along the lines discussed by Flitman and Hurrion (1987).

Although work on the VI cockpit has yet to commence, a typical example of the screen layout envisaged is shown in Figure 3.

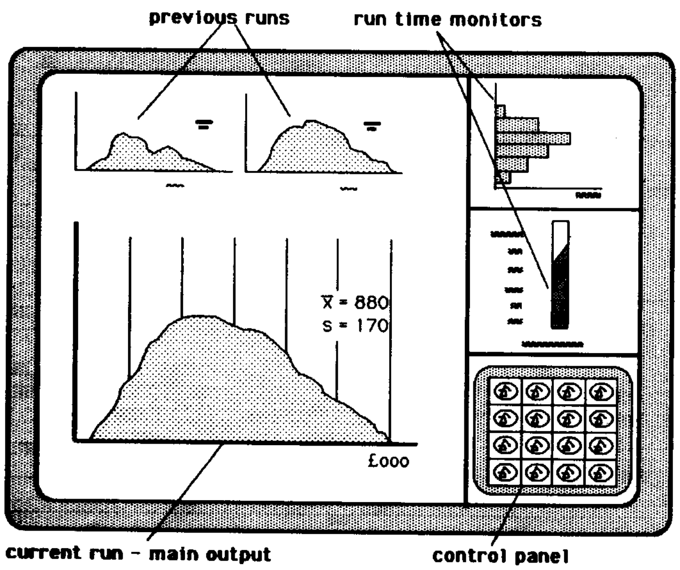

Figure 3 — The VI Cockpit

With each simulation iteration, the cost-time status is updated on the screen. When the user feels the system is sufficiently stable, the iteration sequence can be terminated. The result may be saved in a screen window at the user's discretion. Following a change in design or control information, the saved status indicators may be compared for an assessment of the cost-time consequences as an aid to selecting the best combined design/control strategy for the project.

CONCLUSION

It has long been argued that pre-tender estimates are best made by data concerning the construction process itself rather than the work in place methods currently in use in the construction industry. The reasoning for this is that construction prices are a function of construction costs which in turn are a function of the construction process as distinct from the construction products. This means the conversion of design decisions into construction resource implications, a task requiring some considerable skill and experience not normally available to pre-tender personnel. The difficulty, of course, is that the conventional tendering system simply does not allow or encourage such an approach by manual methods and has led us to the examination of simulation methods as a possible solution.

The increasing research in simulation through techniques such as KBS systems, automatic planners, and Monte Carlo methods suggests that the necessary technology is already available for the task. In principle, the various components -- design/activity, activity/planning, planning/scheduling, scheduling/pricing -- exist in various stages of development. Similarly, the treatment of uncertainty by probabilistic/stochastic simulation is quite advanced even if only at research level.

The purpose of this paper has been to give a brief introduction to each of these disparate developments and show how they naturally join together into the cost-time forecasting system outlined above. This system is currently undergoing development by a team of researchers lead by the authors in collaboration with the Salford University's Information Technology Institute, a commercial design organisation, and construction companies. The work is anticipated to reach completion within the next two years.

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Notes